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CONFLICT DISTRIBUTION PREDICTION AND OPTIMIZATION OF AIRCRAFT IN GROUND MOVEMENTS

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ABSTRACT

During the participation in the 2018 International Conference on Air Transport Research, "ICRAT" the scientific community of air transport stressed the importance of traffic control within airport taxiways.
Scheduling aircraft (ASCP) is addressed in this document for taxiways (single-track road). For different aircraft categories, a detailed examination of the variable response to aircraft delay is provided. A heuristic method based on the prediction of the global conflict distribution (CDPG) is the first approach presented. In the CDPG, two problems that restricted the implementation of the system are fixed: the impasse situation and an optimal travel strategy. The second part details a "first come, first served"(FCFS) planner to develop an integrated departure and arrival management system at Mohamed V Airport. Improved traffic flow management has been implemented to take into account directional constraints on traffic lane links as well as crossing constraints at traffic lane intersections. Rather than using preset itineraries, a route assignment mechanism is added. Scheduling is applied to each route.
Numerical experiments demonstrate an optimal solution for the CDPG in a very short calculation time can be achieved.

Keywords : *Air traffic management (ATM), first-come first-served (FCFS),, Aircraft scheduling (ASCP) ,Information System, Conflicts distribution*

1. INTRODUCTION

The constant increase in air traffic poses various problems, including aircraft grounding. This problem is becoming more and more complex and involves different stages. Ground movements are one of the main factors. Especially for aerodromes that do not have the surface radar and where a significant number of aircraft share limited resources such as routes between the gate and the runway. The growth in traffic aggravates the problem of ground traffic, which leads us to seek solutions to minimize delays and improve ground traffic management.
A number of investigations were conducted to provide guidance to air traffic controllers for decision-making on the ground. In this model, the impact of delays incurred on flights within the airport has been examined. Complexity in calculation depends on the growth of aircraft activity in the airport : more traffic, the more complex the calculation will be. [12]

Aircraft Scheduling Programming (ASCP) determines the optimal routes for a set of aircraft to minimize delays based on taxiway capacities and a series of operational constraints. Aircraft scheduling plays an essential role in the management and operation of a complex system of ground movements within an airport.
The aircraft schedule provides arrival and departure times for all aircraft on the ground at each node. In actual airport operations, aircraft are strictly planned and ordered according to a known schedule.
Over the past few decades, many studies have examined ASCP. ASCP is known to help find the optimal solution to the scheduling problem. In order for the aircraft to be placed on the runway in

time, techniques based on dynamic programming have been proposed [1].
Another study presented a solution for scheduling departures on the runways using linear programming (MILP) [2][3][4].
Some studies have increased airport demand by predicting flight departure times [5].
ASCP is known to be NP-hard and the optimal solution may not be available on a large scale. [6].
Many optimization techniques are applied in ASCP algorithms to obtain a satisfactory solution, including the Branch-and-Bound procedure [7]. Despite the enormous computing speed of supercomputers, ASCP resolution still takes an unreasonably long time, and the solution obtained is only partially optimal, if not approximate.
Today, with the development of the IT industry, computerised systems allow air traffic controllers to implement their manual methods more efficiently. In addition, some operational simulations focused mainly on operating aircraft according to a known schedule. The behavioural characteristics of airport systems and security requirements can be well illustrated by simulation approaches. Simulation models are considered a test environment rather than a planning tool.
However, as a scheduling tool, the development of the approach faces two main obstacles: which are the formation of an aircraft dead end, and a poor quality scheduling plan.
The modelling of aircraft ground movement in an airport platform contains one-way lanes (taxiway). A situation of deadlock may arise in which a number of aircraft cannot continue their journey.
Once the impasse is resolved in the conflict zone, it will quickly spread to the entire airport platform. The mechanism of the aircraft deadlock formation is still unexplainable in the field of airport operations, particularly in ground movement management. Some of the algorithms proposed to avoid deadlock is rather conservative, resulting in an unnecessary waste of infrastructure resources [8]. Avoiding the impasse was still a great challenge in synchronous simulation and real time dispatching system. In addition, current simulation methods generally depend on the experience of air traffic controllers. This is how the solution generated by the simulation method can be significantly diverging from the optimal solution.
However, if these barriers are effectively resolved, the schedule obtained by the simulation method can provide more reliable and flexible services. Airport simulations can handle complex scenarios and accurately describe the operational behaviour of aircraft. In addition, in the field of aircraft reprogramming, it would be a powerful tool that could be used to help air traffic controllers react quickly, particularly in the event of an emergency.
Compared to published approaches, the model and method proposed in this document may have the following distinctive characteristics for a given node link model and schedule:
Scheduling method based on an algorithm taking into account direction, general and transverse traffic lanes and separations as a function of wake turbulence between aircraft on the ground.

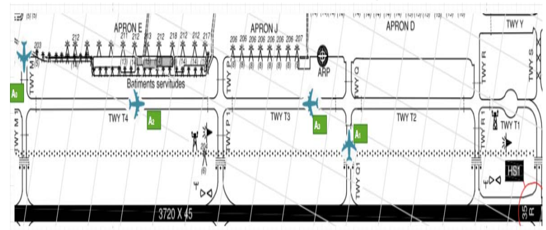

Figure 1 : Example of a single-track taxiway

The mixed integer non-linear programming model is designed for ASCP in an airport system for ground motion management (one-way track). The model integrates many factors into the actual aircraft distribution process, such as several spacing between aircraft (wake turbulence) and taxiway capacity. The model here is characterised by its ability to study the variability of aircraft in terms of delay significantly. This is particularly true for the capacity of the traffic lanes.
A heuristic method using the global Conflicts-Distribution-Prediction-Ground (CDPG) approach is used. It is based on a simulation framework based on a dynamic event-driven system. The two obstacles mentioned above are eliminated by the heuristic method. [9]
The mechanism for forming the aircraft deadlock. A method of avoiding deadlocks is proposed. It ensures that no impasses will occur and at the same time improves the use of infrastructure resources.
The mechanism for optimizing the decision to move on the ground is explored when modelling aircraft movement. On the basis of a global distribution analysing conflicts between aircraft, the almost optimal route choice decision is made so that the system's performance is close to optimal.
This article presents an adaptive algorithm based on FCFS and CDPG based on an article on railway planning [9] and aircraft ground scheduling [10]. This algorithm, however, did not allow trains to be rerouted, preventing them from exploring the full space of the solution. This algorithm facilitates aircraft rerouting, ensuring overall optimality. The following section describes in detail the

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organization of this document. The scientific formulation of the ASCP is detailed in Part 2. In part 3 to solve the ASCP a heuristic approach is suggested based on the CDPG. Part 4 contains the results and discussions. Part 5 concludes this document.

2. MODEL STATEMENT

This study focuses on an airport platform at Mohammed V Airport, specifically ground movements as shown in figure 1. Aircraft meet and move on different paths from the airport or at intersections. It is assumed that each aircraft has a pre-established departure time at its original parking lot. Aircraft operating directions are classified into two types : Track-Parking and Parking-Track-Parking.

Mohammed V Airport (annexe 1, annexe 2) [11] has two runways, 35R/17L and 35L/17R, each with its own type of movement. This configuration is called specialized runways according to ICAO (International Civil Aviation Organization). To better models and project this study in the field, the scenario is as follows :

- Graph G = (V, E) where the V vertices are the airport points (position, holding point and intersection).
- The traffic lanes are represented by arches.
- Runway 35R/17L is operational, and intended for the landing and take-off at the same time.

Two oriented graphs have been developed. The first graph (annexe 3) is dedicated to the takeoff and the second (annexe 4) to landing. The purpose of this separation is to better visualize the different paths for each case [12].

The model takes into account some factors that influence aircraft sensitivity to delays, such as aircraft types and ground track. In addition, the complex behaviours of aircraft near the runway are targeted. When aircraft enter or leave a runway, airport air traffic controllers must organize the routes of arriving or departing aircraft. The model takes into account all possible conflicts between aircraft that occupy the airport's resources. In the same way, the airport capacity is considered in this model. It corresponds to the maximum number of aircraft that can operate on Taxiways. Some previous works have made sure that the number of aircraft on the ground does not exceed the maximum capacity of the airport. In this document, the choice of the aircraft path is adapted in the model to avoid discretizations of the time horizon. Time lost due to deceleration, waiting time at waiting points or intersections is also taken into account. Obviously, the model is closer to actual airport operations than to literature. This makes it particularly interesting and also makes it easier from an operational point of view for a real implementation in the field.

2.1.Notations

This is similar to the representation used in [9].
To clearly introduce the optimization model, it is necessary to express the following ratings.
In table 1, the indices used in the expressions are noted. The parameters are given in table 2. In table 3, the different variables are listed.

Table 1 : Indices used in the expressions

Symbol	Description
a_1, a_2	Aircraft index.
n, n^+	Node Index
i	Taxiway or runway clue.
V	All of all aircraft.
V^p	All aircraft heading to the parking lot.
V^r	All aircraft heading for the runway.
N_{a_1}	All Nodes on the aircraft's route a_1.
$l_{u,n}$	All taxiways possible from the aircraft a_1 on a node $n(n \in N_{a_1})$

Table 2 : Parameters

Symbol	Description
$L_{n,n+}$	Distance between node a_1 and node n^+
$f_{a_1}^{n,n^+}$	Free time for the aircraft a_1 on the section between the node n and its next node $n(n,n^+ \in N_{a_1})$
F_{a_1}	Free time of the aircraft a_1 over its entire route
$w_{a_1,n}$	a_1 Aircraft waiting time at the node n
h^{aa} / g^{aa}	Arrival-Arrival Interval, i.e. the time required to organize aircraft arrival routes when two aircraft arrive sequentially at the same node. h^{aa} is the interval for aircraft with the same direction, and g^{aa} is that of aircraft with an opposite direction.
h^{dd} / g^{dd}	Difference between two departures, i.e. the time required to organize the aircraft departure routes when two aircraft leaves the same node sequentially. h^{dd} is the difference between aircraft with the same direction, and g^{dd} is that of aircraft with an opposite direction.

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h^{da} / g^{da}	Difference between departure and arrival, i.e. the time required to organize the itinerary of arriving aircraft after organizing the aircraft's itinerary from the node. h^{da} is the difference for aircraft with the same direction, and g^{da} is that of aircraft with an opposite direction.
h^{ad} / g^{ad}	Difference between arrival and departure, i. e. the time required to organize the itinerary for departing aircraft after organizing the itinerary for the arriving aircraft. h^{ad} is a difference for aircraft with the same direction, and g^{ad} is that for aircraft with an opposite direction.
$t_{a_1}^0$	a_1 The aircraft's scheduled departure time from its parking lot.
τ_b	Aircraft Running Time at the Node
$\tau_{a_1,e}^a$	Loss of additional aircraft time a_1 for acceleration when stopping the aircraft a_1 from the node.
$\tau_{a_1,e}^d$	Loss of additional aircraft time a_1 for deceleration when the aircraft has a_1 to stop at the next node.
M	Constant large enough.

Table 3 : Variables

Symbol	Description
$t_{a_1,n}^a$	Time of arrival of the aircraft a_1 at the node n
$t_{a_1,n}^d$	Departure time of the aircraft a_1 from the node n
Δt_{a_1}	Aircraft delay time a_1
$\xi_{a_1,a_2,n}^{aa}$	Binary variable, if the aircraft a_1 arrives earlier at the node n than the aircraft a_2, then $\xi_{a_1,a_2,n}^{aa} = 1$ if not $\xi_{a_1,a_2,n}^{aa} = 0$
$\xi_{a_1,a_2,n}^{dd}$	Binary variable, if the aircraft a_1 leaves the node earlier n than the aircraft a_2, then $\xi_{a_1,a_2,n}^{dd} = 1$, if not $\xi_{a_1,a_2,n}^{dd} = 0$
$\xi_{a_1,a_2,n}^{da}$	binary variable, if the aircraft a_1 leaves the Node n before the aircraft reaches the node n, then $\xi_{a_1,a_2,n}^{da} = 1$ if not $\xi_{a_1,a_2,n}^{da} = 0$
$\xi_{a_1,a_2,n}^{ad}$	Binary variable, if the aircraft a_1 arrives at the node n before the aircraft leaves a_2 the node n, $\xi_{a_1,a_2,n}^{ad} = 1$ Otherwise $\xi_{a_1,a_2,n}^{ad} = 0$
$\varsigma_{a_1,n}^i$	Binary variable, if the aircraft u occupies the track (taxiway) i at node r, then $\varsigma_{a_1,n}^i = 1$, otherwise. $\varsigma_{a_1,n}^i = 0$
$\varsigma_{a_1,a_2}^{n,n^+}$	Binary variable, which is used to describe the priorities of aircraft in the opposite direction to occupy the same segment. If the aircraft a_1 is occupied before the segment between the node n and the aircraft a_2 node n^+, then $\varsigma_{a_1,a_2}^{n,n^+} = 1$ if not $\varsigma_{a_1,a_2}^{n,n^+} = 0$
$\delta_{a_1}^n$	binary variable, which is used to indicate if the aircraft a_1 stops at the node n. If the aircraft a_1 stops at the node n, then $\delta_{a_1}^n = 1$ Otherwise $\delta_{a_1}^n = 0$

2.2 Optimization model

The ASCP optimization model for ground motion is described as follows :

- Constraints related to waiting points

$$t_{a_1,n}^a + w_{a_1,n} + \tau_b \le t_{a_1,n}^d \quad \forall a_1 \in V; n \in N_{a_1} \quad (1)$$

- Stopping/non-stopping constraints :

$$M.\delta_{a_1}^n \ge t_{a_1,n}^a + \tau_b - t_{a_1,n}^d \quad \forall a_1 \in V; n \in N_{a_1} \quad (2a)$$

$$M.\delta_{a_1}^n \ge t_{a_1,n}^d - t_{a_1,n}^a - \tau_b \quad (2b)$$

$$M.(1-\delta_{a_1}^n) > t_{a_1,n}^a + \tau_b - t_{a_1,n}^d \quad (2c)$$

- Free running time constraints :

$$t_{a_1,n}^d + f_{a_1}^{n,n^+} + \delta_{a_1}^n.\tau_{a_1,e}^a + \delta_{a_1}^{n^+}.\tau_{a_1,e}^d \le t_{a_1,n^+}^a$$

$$\forall a_1 \in V; n, n^+ \in N_{a_1} \quad (3)$$

- Arrival-Arrival flow constraints :

$$t_{a_1,n}^a + h^{aa} \le t_{a_2,n}^a + (1-\xi_{a_1,a_2,n}^{aa}).M \quad \forall a_1, a_2 \in V^r$$

$$\text{or } a_1, a_2 \in V^p, a_1 \ne a_2; n \in N_{a_1}, N_{a_2} \quad (4a)$$

$$t_{a_1,n}^a + g^{aa} \le t_{a_2,n}^a + (1-\xi_{a_1,a_2,n}^{aa}).M$$

$$\forall a_1 \in V^r, a_2 \in V^p$$

$$\text{or } a_1 \in V^p, a_2 \in V^r; n \in N_{a_1}, N_{a_2} \quad (4b)$$

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$\xi^{aa}_{a_1,a_2,n} + \xi^{aa}_{a_2,a_1,n} = 1$ (4c)

- Departure-Departure flow constraints :

$t^d_{a_1,n} + h^{dd} \le t^d_{a_2,n} + (1-\xi^{dd}_{a_1,a_2,n}).M \ \forall a_1,a_2 \in V^r$

or $a_1,a_2 \in V^p, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}$ (5a)

$t^d_{a_1,n} + g^{dd} \le t^d_{a_2,n} + (1-\xi^{dd}_{a_1,a_2,n}).M$

or $a_1 \in V^p, a_2 \in V^r; n \in N_{a_1}, N_{a_2}$ (5b)

$\xi^{dd}_{a_1,a_2,n} + \xi^{dd}_{a_2,a_1,n} = 1 \ \forall a_1,a_2 \in V, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}$ (5c)

- Arrival-Departure flow constraints :

$t^a_{a_1,n} + h^{ad} \le t^d_{a_2,n} + (1-\xi^{ad}_{a_1,a_2,n}).M \ \forall a_1,a_2 \in V^r$

or $a_1,a_2 \in V^p, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}$ (6a)

$t^d_{a_1,n} + g^{ad} \le t^d_{a_2,n} + (1-\xi^{ad}_{a_1,a_2,n}).M \ \forall a_1 \in V^r, a_2 \in V^p$

or $a_1 \in V^p, a_2 \in V^r; n \in N_{a_1}, N_{a_2}$ (6b)

- Departure-Arrival flow constraints :

$t^d_{a_1,n} + h^{da} \le t^a_{a_2,n} + (1-\xi^{da}_{a_1,a_2,n}).M \ \forall a_1,a_2 \in V^r$

or $a_1,a_2 \in V^p, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}$ (7a)

$t^d_{a_1,n} + g^{da} \le t^d_{a_2,n} + (1-\xi^{da}_{a_1,a_2,n}).M$

or $a_1 \in V^p, a_2 \in V^r; n \in N_{a_1}, N_{a_2}$ (7b)

- Correlation constraints between $\xi^{ad}_{a_1,a_2,n}$ and $\xi^{da}_{a_1,a_2,n}$

$\xi^{ad}_{a_1,a_2,n} + \xi^{da}_{a_1,a_2,n} = 1 \ \forall a_1,a_2 \in V, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}$ (8)

- Tracing constraints

$\xi^{dd}_{a_1,a_2,n} = \xi^{aa}_{a_1,a_2,n^+} \ \forall a_1,a_2 \in V^r$

or $a_1,a_2 \in V^p, a_1 \ne a_2; n,n^+ \in N_{a_1}, N_{a_2}$ (9)

- Meeting-Crossing constraints :

$t^a_{a_1,n^+} + g^{ad} \le t^d_{a_2,n^+} + (1-\zeta^{n,n^+}_{a_1,a_2}).M \ \forall a_1 \in V^r, a_2 \in V^p$

or $a_1 \in V^p, a_2 \in V^r; n; n^+ \in N_{a_1}, N_{a_2}$ (10a)

$\zeta^{n,n^+}_{a_1,a_2} + \zeta^{n,n^+}_{a_2,a_1} = 1 \ \forall a_1 \in V^r, a_2 \in V^p$

or $a_1 \in V^p, a_2 \in V^r; n; n^+ \in N_{a_1}, N_{a_2}$ (10b)

- Nodes d'intersection capacity constraints :

$\sum_{i|i \in la_1,n} \varsigma^i_{a_1,n} = 1 \ \forall a_1 \in V; n \in N_n$ (11a)

$t^d_{a_1,n} + h^{da} \le t^a_{a_2,n} + (1-\xi^{aa}_{a_1,a_2,n}).M + (1-\varsigma^i_{a_1,n}).M + (1-\varsigma^i_{a_2,n}).M$

$\forall a_1,a_2 \in V^p$

or $a_1,a_2 \in V^r, a_1 \ne a_2; n \in N_{a_1}, N_{a_2}; i \in l_{a_1,n}, l_{a_2,n}$ (11b)

$t^d_{a_1,n} + g^{da} \le t^a_{a_2,n} + (1-\xi^{aa}_{a_1,a_2,n}).M + (1-\varsigma^i_{a_1,n}).M + (1-\varsigma^i_{a_2,n}).M$

$\forall a_1,a_2 \in V^p$

or $a_1,a_2 \in V^r; n \in N_{a_1}, N_{a_2}; i \in l_{a_1,n}, l_{a_2,n}$ (11c)

- Departure time constraints :

$t^d_{a_1,0} \ge t^0_{a_1} \ \forall a_1 \in V$ (12)

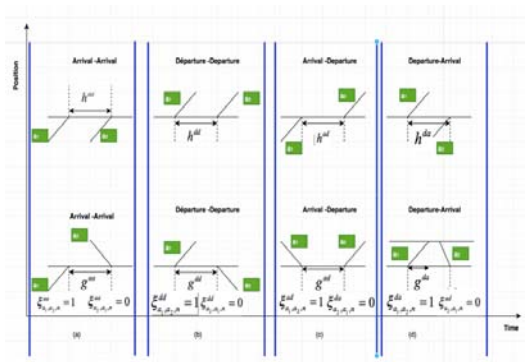

Figure 2 : Several interval scenarios for aircraft for one node or intersection

Constraints (2a) - (2c) reflect the relationship between the arrival and departure times of an aircraft from a node in two cases, stop and non-stop. The binary variable $\delta^n_{a_1}$ is added to indicate if the aircraft a_1 stops at the node n. Constraints (2a) and (2b) establish the relationship between the arrival and departure times of an aircraft in the event of non-stop flight, i.e. $t^a_{a_1,n} + \tau_b = t^d_{a_1,n}$ $if\,\delta^n_{a_1} = 0$

While the constraints (2c) relate to the case of aircraft stopping at the node, i. e. $t^a_{a_1,n} + \tau_b < t^d_{a_1,n}$ $if\,\delta^n_{a_1} = 1$.

The constraint (6) establishes a correlation between the entry and exit times of an aircraft on a section (taxiway). If a stoppage occurs, two additional time losses $\tau^a_{a_1,e}$ and $\tau^d_{a_1,e}$ are considered. They are caused by the aircraft's acceleration from the node and the deceleration of the aircraft as it reaches the node.

In the unidirectional taxiway, when aircraft are approaching or leaving a node, air traffic controllers must prioritize the aircraft's paths.. When two consecutive aircraft arrive or depart, a time interval must be respected and the routes for the different aircraft must be organized. Some flow

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parameters of the different scenarios are described in figure 2, and these flows can refer to [9].

Constraints (4) - (7) present the relationship between the arrival or departure time of two consecutive aircraft to ensure these flows. Thus, the constraints (4) ensure that the time lapse between the arrival times of two successive aircraft is greater than or equal to parameters h^{aa} or g^{aa}. The h^{aa} factor is the Arrival-Arrival interval between two aircraft following each other and moving in the same trajectory. g^{aa} represents the distance between the arrival and arrival of two successive aircraft moving in opposite directions. The $\xi^{aa}_{a_1,a_2,n}$ decision variable indicates the priority level when two aircraft arrive at the node.
The constraint (4c) ensures there is only one non-zero value between $\xi^{aa}_{a_1,a_2,n}$ and $\xi^{aa}_{a_2,a_1,n}$. Similarly, equations (5) - (7) present respectively the spacing constraints between two consecutive departures, and the spacing constraints between departure and arrival.
The constraints (8) highlight the correlation between $\xi^{ad}_{a_1,a_2,n}$ and $\xi^{da}_{a_2,a_1,n}$.
The constraints (9) relate to the tracing behaviour of two aircraft in the same direction in a segment (taxiway). In other words, this means that the exceedance behavior cannot occur in the segment.
The stresses (10) determine the crossing characteristics between two aircraft moving in opposite directions. If two aircraft operating in opposite directions occupy the same section simultaneously, one of them must wait at the node so that the other can cross. The binary variable $\varsigma^{n,n^+}_{a_1,a_2}$ is used to characterize the aircraft a_1 and a_2 priority hierarchy and for the segment between the two nodes n and n^+.
The constraints (11) are focused on the boundaries of the nodes at intersections. In most cases, the node load is a function of the number of lanes (taxiway). Here, it is considered that a taxiway at a crossroads is only used by one aircraft at a time. Thus, at any given time, the number of aircraft travelling in the taxiway may not exceed the capacity of the node. Here, the choice of the aircraft taxiway is also adopted, but to reflect the capacity of the node.

Figure 3 : General framework of the heuristic approach

The binary variable $\varsigma^{i}_{a_1,n}$ indicates whether the aircraft a_1 selects the track i in the node $(n \in N_{a_1})$.

If that's true, then $\varsigma^{i}_{a_1,n} = 1$, if not $\varsigma^{i}_{a_1,n} = 0$. The constraints (11a) indicate that an aircraft can only contain one lane for a certain node. If two aircraft choose the same node, one aircraft must arrive at the node after the other aircraft leaves the node. In addition, Departure-Arrival spacing between them is guaranteed (see constraints (11 b) and (11 c)). It is clear that the constraints (11 b) and (11 c) ensure that each lane (taxiway) is operated and can only be served by one aircraft at a time, while ensuring that the number of aircraft is lower than the maximum capacity available at all times.
In this simulation, it is assumed that each aircraft has its pre-defined departure time from its initial parking lot. The constraint (12) ensures that the aircraft's actual time of departure. from its original parking lot must not be earlier than the scheduled time of departure.

3. HEURISTIC APPROACH USING CONFLICT DISTRIBUTION PRODUCTION

3.1 General framework of the heuristic approach

Section 3 presents a complex non-linear programming in integers mixes for ASCP. A large number of binary variables, such as $\xi^{aa}_{a_1,a_2,n}$,, $\xi^{dd}_{a_1,a_2,n}$ $\xi^{ad}_{a_1,a_2,n}$,,, $\xi^{da}_{a_2,a_1,n}$ make it difficult to solve the model. It is therefore necessary to design an effective method adopted for aircraft [9].
To achieve faster and more efficient planning, figure 3 illustrates the general context of the heuristic method suggested in this article. Based on

a simulation of aircraft movement on the ground, the arrival and departure times of each aircraft at the node can be established.. Two important features of the heuristic method are to explain precisely the mechanism of blockage formation and to present a mechanism for optimizing the aircraft movement strategy based on the prediction of the global distribution of ground conflicts. This is why the heuristic method is called " CDPG " in the following description.

As shown in figure 3, the CDPG consists of two parts: the determination of aircraft macro-states and the dynamic update of the system by events.

The first part is crucial, it decides whether a feasible and high quality planning plan is obtained. First, two aircraft statuses, namely " en mouvement " and " à arrêt ", are defined to reflect two different aircraft movement strategies.

In section 3.2, three decision-making processes are described assessing aircraft condition. As a result, it can be seen that the displacement system is based on three elements: the information obtained, the deadlock control system and the optimization system based on the forecast of the conflicting distribution.

The determination of aircraft states actually reflects the values of a large number of binary variables in the model, such as $\xi^{aa}_{a_1,a_2,n}$, $\xi^{dd}_{a_1,a_2,n}$ $\xi^{ad}_{a_1,a_2,n}$,,,, $\xi^{da}_{a_2,a_1,n}$.

Section 3.2.1 specifies that, in some scenarios, aircraft condition can only be determined on the basis of local information.

The blocking control mechanism in section 3.2.2 and the aircraft route optimization in section 3.2.3 are represented by green rectangles in figure 3. These are two central modules of the CDPG. The purpose of this procedure is to determine, after analysis of the deadlock formation process, whether or not the ground movement conditions of an aircraft are conducive to the occurrence of a deadlock. This proposed deadlock control procedure effectively prevents the deadlock of aircraft while optimizing infrastructure management.

In the travel optimization module, a local conflict management strategy is applied to predict the overall distribution of conflicts between aircraft. Depending on the outcome of the conflict distribution, aircraft states are designed to reduce aircraft delay costs as much as possible.

Section 3.5 describes in more detail the operating behaviour of aircraft according to aircraft traffic conditions. An aircraft speed coordination mechanism is used to determine the speed of moving aircraft. The coordination scheme also provides that the operating behaviour of aircraft shall be subject to the modelling constraints referred to in Part 2.2.

The CDPG is the result of the discrete dynamic event system. In the proposed discrete event model [10], the arrival or departure of aircraft is considered as an " événement ", which leads to a progressive update of the system. In section 3.6, the concept of événement est is further expanded to analyze all possible aircraft behaviours. For example, a Departure-Start - Departure Interval event is defined to describe the behaviour of the aircraft under stress (8) in the model. From the analysis of all the potential events described in section 3.6, we can obtain a modular time slot, which will condition the updating of the entire system.

3.2. Analysis of aircraft movement decisions

3.2.1. Aircraft movement decision based on information obtained

Aircraft states are classified into three categories: " en mouvement ", " à l'arrêt " and " indéterminé ".

The status of " mouvement " means that the aircraft can move to its front node.

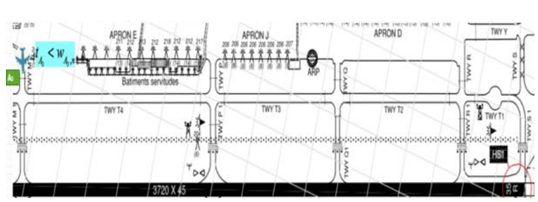
The "Stop" indication is used to inform the aircraft of the need to stop at the node or on the taxiway.

The aim is to establish the aircraft condition between "undetermined" and "moving" or "stationary".

In some specific scenarios, aircraft movement strategies can only be explicitly judged on the basis of local information. Figure 4 shows these scenarios in which the aircraft A_0 (the priority aircraft) has a single travel strategy.

a) The aircraft A_1 is A_0 at the node (stopping point) (see figure 4(a)). Of course, the aircraft must stop at the node until its waiting time is over. In figure 4(a), t_{A_0} is the time that the aircraft A_0 has already spent on waiting time.

Figure 4a



b) If the opposite aircraft operating in the segment following the aircraft A_0, the aircraft must stop at the node (stopping point) (see figure 4(b1)). If the A_1 opposite aircraft is in a

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state of movement from the next node following the aircraft A_0, the aircraft must stop at the current node (see figure 4(b2)). It should be noted that, if the condition of the aircraft is unknown in figure 4(b2) then it is impossible to make an assessment of the condition of the aircraft. It reflects a locking mechanism between aircraft, i.e. states A_0 and A_1 are dependent on each other. The condition of the aircraft A_0 is influenced by the difference between departure and departure. As presented by constraint (5) in section 2.2,

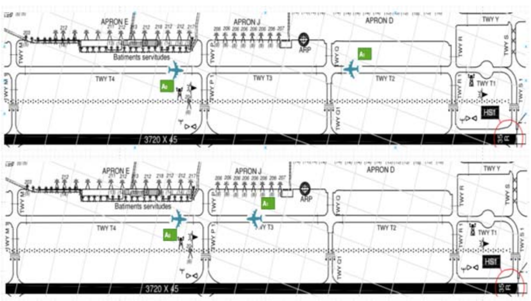

Figure 4b

When two aircraft passes through the same node, the departure/departure separation between these two aircraft must be respected. In figure 4(c), the aircraft A_0 must stop. In figures 4(c1) and (c2), t_{A_1} is the time the aircraft A_1 spent after leaving the node.

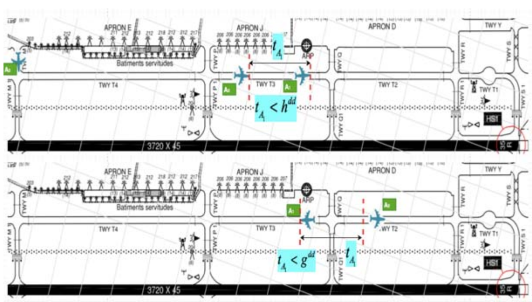

Figure 4c

c) The condition of the aircraft A_0 is influenced by the limited capacity of the node. In figure 4(d), the aircraft A_1 travels in the segment to the hot spot (intersection node) of the aircraft A_0, and will occupy a frontal taxiway. However, there is no clear path for the aircraft A_1 Obviously, the aircraft A_0 must leave the track tied to its node in order to clear the track before the aircraft A_1 arrives at the track. Here, it should be noted that if the aircraft is A_0 required to stop at the track associated with the crossing node for any reason, the aircraft A_1 will arrive at the node after the aircraft leaves the A_0 track. Coordination between the departure time of A_0 and arrival time of A_1 aircraft is resolved by the speed coordination mechanism between aircraft presented in section 3.5.

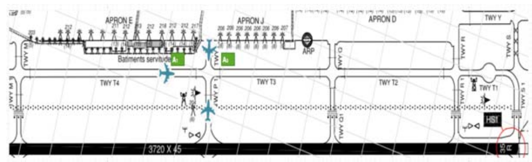

Figure 4d

It can be deduced from the above that the condition of the identified aircraft can only be reduced from an "indeterminate" state to a "stop" state if local information is available. Under the CDPG, aircraft decisions must be cautious, ranging from " indéterminé " to " en mouvement ", and successfully pass the deadlock control mechanism and optimization mechanism. Impasse verification is a mechanism that distinguishes between the fact that an aircraft's "in motion" decision leads to an impasse, while the optimization mechanism determines whether a "in motion" decision is likely to promote a global distribution of aircraft conflicts between them in the field.

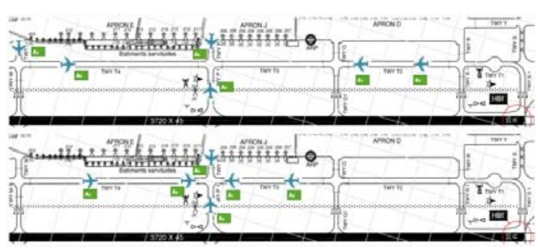

Figure 5 : Several aircraft deadlock

3.2.2. Mechanism for forming and resolving an aircraft deadlock

3.2.2.1. Aircraft blocking situation.

In practice, an aircraft should not be allowed to enter a segment (taxiway) if its movement leads to

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a real deadlock. A deadlock situation occurs when all aircraft are blocked by others and none of them can continue to operate. In figure 5, several scenarios of deadlock formations are illustrated.In the first scenario figure 5(a) of deadlock, the aircraft A_2 and A_3 are blocked (in the taxiway T4, taxiway T3 segments) because the lanes (taxiway) have been occupied by the aircraft A_0 and A_1.

In the second scenario figure 5(b), all aircraft are blocked in the node (intersection point) by two " bouchons " on the left, right and opposite sides. La mention " bouchon " indique que le nombre d'aéronefs dans la même direction est équivalent au nombre de voies au nœud (intersection). Once a dead end is formatted in any area, there will be no way out of the impasse that is approaching and the entire ground traffic system will quickly be plunged into a state of paralysis. Therefore, an impasse should be avoided when modelling aircraft movement. Determining whether there is an impending impasse is a NP-HARD problem [15]. Finding a practical solution to resolve deadlock problems is always a great challenge for air traffic controllers.

Finding an algorithm that guarantees to block while making the best use of resources or minimizing the total travel time of all devices is a very interesting thing to do. Previous deadlock avoidance methods focus on how to end the circular waiting period. However, it may be useful to study the mechanism of the aircraft deadlock formation from a new perspective, i. e. the formation of an aircraft plug.

3.2.2.2. Mechanism for forming the aircraft impasse.

Above all, it is about a specific problematic, in which there may be a potential deadlock, but in which a real one can be avoided. As shown in figure 6(a), the aircraft A_1 and A_2 are at nodes N_0 and N_2, and the aircraft A_0 moves on the segment between N_0 (taxiway T4) and N_1 (taxiway T3,taxiway Q1). Due to a wrong decision, a deadlock may occur (see figure 6(b)). However, the blocking situation can be avoided by controlling the aircraft sequence based on local information. For example, one can first determine the priority of the aircraft A_1 and A_2 for the occupation of the related segment N_1. Definitely, the aircraft A_2 has absolute priority over the aircraft and A_1 A_0 to avoid the situation in figure 6(b). And the aircraft A_1 arrives at the node N_1 until the aircraft leaves A_0 the node (N_1 see figure 6(c)). A speed coordination mechanism introduced in section 4.3 is adopted to achieve this sequential control, while ensuring several aisles between aircraft, which are presented in constraints (4) - (8) of the model.

Clearly, the situation described in figure 6(a) does not lead to a real deadlock in ground movement. A real impasse originates in the formation of an aircraft plug in the taxiway, which is observed in the impasse scenarios illustrated in figure 5. The cause of this impasse is a contradiction between the number of aircraft on the ground and the restricted number of taxiways. The conditions that form the impasse in which the aircraft finds itself are presented as follows

Figure 6a

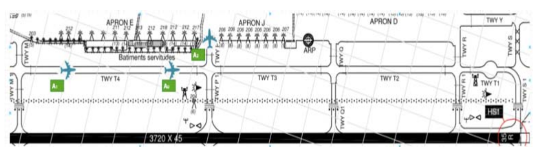

Figure 6b

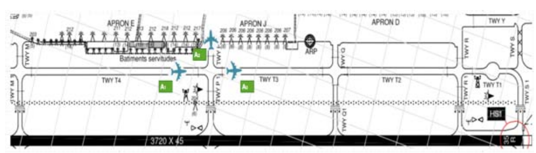

Figure 6c

Figure 6 a, b, c : Scenarios of false deadlock

3.2.3. Mechanism for optimizing aircraft movements based on the prediction of conflict distribution

The optimal ASCP solution is to obtain the optimal aircraft sequences for occupying infrastructure resources, such as taxiways and nodes. In terms of the structure of the scheduling plan, there is an optimal distribution of conflict points in the optimal scheduling plan. Here, the conflict point is the point at which the routes cross in the scheduling plan (see figure 7).

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And in this approach, the ASCP was used to route the aircraft, which was then transmitted to the FCFS model, such as [9] [10]

For simulation approaches, the optimal order of aircraft for occupying airport platform resources is linked to the optimal aircraft movement strategies in their routes. For example, in figure 4(b2), it is necessary to decide on the priority of aircraft A_0 and A_1 for the occupation of sectoral resources.

Better travel strategies will result in a rational distribution of conflicts. However, due to an unknown schedule, it is necessary to consider how to assess the influence of aircraft ground movement decisions on conflict distribution.

The first-come, first-served (FCFS) principle is a well-known allocation rule that has been widely applied in the airport and rail distribution system. Some priority rules are also studied, which are related to the types of devices. Air traffic controllers hope to optimally organize resources so that aircraft achieve system optimality (SO).

The application of these local search techniques allows the local optimum to be obtained, which can be very far from (SO). However, these local search techniques are very effective in obtaining an achievable aircraft planning plan. Through these local search techniques, information on conflicts between aircraft can be obtained quickly. It may be useful to analyse the influence of different aircraft ground traffic decisions on the distribution of conflicts.

The fundamental concept of the optimization scheme described in this section is to test the choices of aircraft movements according to the conflict distribution obtained by the FCFS. The case described in figure 7 illustrates the optimization mechanism. As shown in figure 7, when the aircraft A_0 arrives at the node at the N_L^- time t, the conflict for the occupancy segment L occurs between the aircraft A_0 and A_1. At the time, the t aircraft was A_1 still operating in the segment L'. According to the FCFS rule, the aircraft A_0 has a higher priority to occupy the aircraft segment L A_1. Figure 7(a) shows the following scheduling plan when the FCFS decision is adopted by A_0. However, in figure 7(b), another decision is adopted by the aircraft A_0.

The A_0 aircraft stands at the node to allow A_1 aircraft to be prioritized for occupying the L portion. Figure 7(b) illustrates the following scheduling plan when A_0 adopting a non-FCFS decision.

It is important to note that the following two diagrams are obtained using the "first come, first served" approach. The focus here is on the distinction between these two planes. In figure 7(a), seven aircraft are slowed down in their travel procedure. While in the non-FCFS version of the strategy adopted by A_0, only four aircraft are delayed. Although the A_0 aircraft has a significant delay cost, the total delay costs of all aircraft in figure 7(b) are lower than those shown in figure 7(a). It is also possible to note that the positions of the contentious points illustrated in figure 7(b) are better distributed than in figure 7(a). The decision of aircraft A_0 that was not an FCSF at time t could therefore be more rational than the decision of the FCSF in the case illustrated in figure 7.

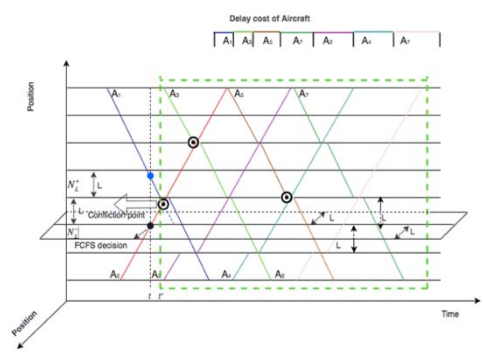

Figure 7a : FCFS

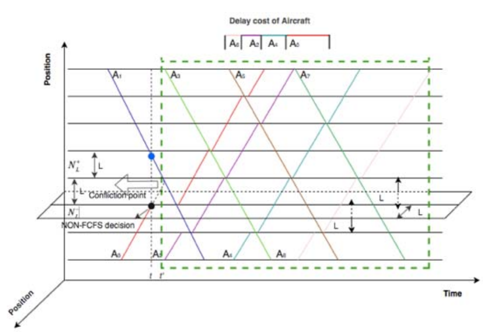

Figure 7b : Non-FCFS

Figure 7 a, b : The subsequent plans of two different scheduling algorithms for aircraft

Based on the above discussions, the optimization procedure can be generated as follows :

First of all, some symbols are presented in the optimization procedure :

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Ω_t the state of the airport platform system at time t, which is described by the position and state of each aircraft at time t.

U_t^N set of aircraft, in which aircraft, the condition of which is undetermined, are recorded at the instant t. It is referred to as $U_t^N = \{A_k \mid k = 1,2,....,n\}$ and n is the number of aircraft overall U_t^N.

ψ_t Final status of the decision, which includes the registration of the specified aircraft and its movement status when the search process is fully executed. These are as follows

$\psi_t = (TD_t^{\min}, A^{\min}, AT^{\min})$

$TD_t^{\min}$ is the minimum total cost of the delay in the following plans obtained by the FCFS,

$A^{\min}$ is the registration of the aircraft corresponding to the minimum total cost of delay,

and $AT^{\min}$ is a binary variable describing the state of the aircraft $A^{\min}$. If $T^{\min} = 1$, the aircraft $A^{\min}$ will adopt the movement strategy. Otherwise, 646 twill stop at the current node.

TD_t is the total cost of delays for all aircraft in the plan obtained by the FCFS.

3.2.3.1. Procedure for optimizing the aircraft's ground motion strategy.

Phase 1 : $A_k\,(k = 1, A_k \in U_t^N)$ is the initial priority aircraft for which the state's decision will be analyzed. Proceed to step 2.

Phase 2 : the movement strategy is adopted for the aircraft A_k at the time t. According to the deadlock control process described in point 3.2.2, the analysis of the possibility of the deadlock occurring on the remaining A_k route is a necessity. If there is no deadlock, the following plan after the time t is obtained on the basis of the FCFS. If $TD_t < TD_t^{\min}$ update i. ψ_t e. $TD_t^{\min} \Leftarrow TD_t$, $A^{\min} \Leftarrow A_k$ and $AT^{\min} = 1$.

The system is reset to the original state Ω_t. Proceed to step 3.

Phase 3 : the shutdown strategy is applied for the aircraft A_k at the time. The following plan after time t is obtained on the basis of the FCFS. Yes, update, i. e. $TD_t^{\min} \Leftarrow TD_{t},,, A^{\min} \Leftarrow A_k$, and $AT^{\min} = 0$. The system returns to the original state Ω_t. Proceed to step 4.

Phase 4 : $k = k+1$ Let's do it. If $k \le n$, return to step 1. Alternatively, if all aircraft in the U_t^N set are examined, the procedure is completed. Depending on the status of the final decision ψ_t, the selected aircraft and its condition are determined.

Some additional explanations are given about the above optimization procedure. First, only the condition of an aircraft can be determined after the optimization procedure for all aircraft in the set has been completed ψ_t. In the ground motion system on one-way taxiways, the states of some aircraft are dependent on each other.

For example, in the case shown in figure 4(b), the aircraft A_1 must stop at the node if the aircraft condition is A_0 in motion. Secondly, when the traffic strategy is applied for the controlled aircraft in step 2, it is possible that a deadlock situation may occur on the remaining route of the controlled aircraft.

The controlled aircraft must therefore pass the deadlock verification procedure. If a deadlock situation can occur, the temporary movement strategy of the verified aircraft is cancelled.

Third, when adopting FCFS to resolve the subsequent scheduling plan in steps 2 and 3, an impasse check is also required for all aircraft.

3.3. Directions of airport taxiways link

To better manage directionality, one of the basic rules is that links for traffic lane segments should be one-way (taxiway). As shown in figure 8, if an aircraft is already moving on a taxiway segment, another aircraft moving in the same direction may enter the segment as explained above as long as an appropriate distance is maintained between the two aircraft (wake turbulence). However, no aircraft may enter the taxiway segment in the opposite direction until the segment is empty.

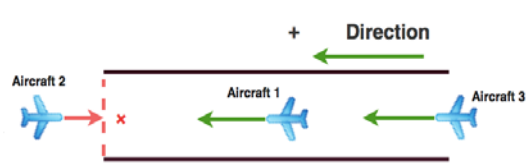


Figure 8 : Availability of routes by direction

Each lane segment is assigned an arbitrary direction (depending on traffic). The number of aircraft in one direction corresponds to a positive account while in the other direction it corresponds to a negative account. Figure 9 shows an example of different availability depending on the direction of movement.
For the positive direction of figure 9(a), the link is available when the account is positive and is smaller than the maximum positive account. For the negative direction in figure 9(b), the link is available when the account is negative and is larger than the minimum negative account. The negative counting concept allows you to know the availability of the link in relation to the current number, maximum number and direction. This pattern is comparable to that of [10].

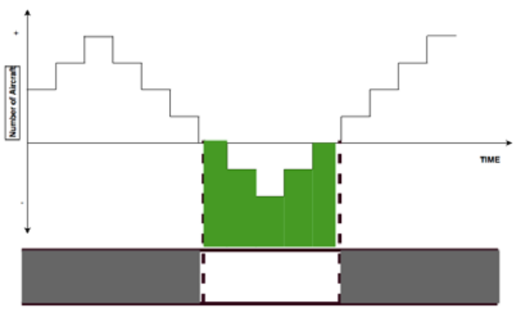


Figure 9a : positive

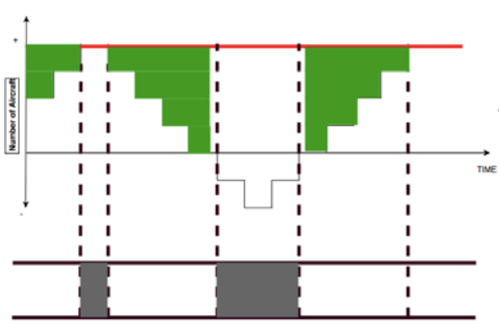


Figure 9b : negative
Figure 9 : The availability of sites according to direction

Case 1 : If a real impasse occurs in a one-way traffic lane. The following two conditions are present : positive and negative traffic congestion is observed on either side of the taxiway, and the number of aircraft operating in the middle is greater than or equal to the number of lanes of the node between these two obstacles.
The above can be broken down into the following two cases.

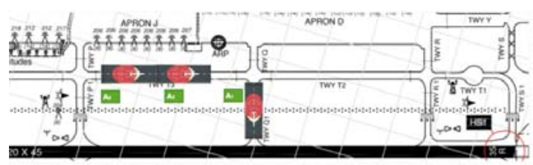
According to case 1, there are three circumstances that constitute a deadlock : positive and negative congestion and a conflict between the number of aircraft and the number of taxiways. In the event of a major impasse, these three conditions are simultaneously met. It is important to note that the relationships between the three conditions mentioned above are progressive and not independent. The relationship between these three conditions can be described as follows :

- 1 : Positive congestion occurs if an aircraft (priority) moves to its next node.
- 2 : Negative congestion is on the remaining route of the priority aircraft if condition (1) exists.
- 3 : The number of aircraft is in conflict with the number of lanes if conditions (1) and (2) exist

3.4 Aircraft Separation Coordination Mechanism Wake Turbulence

Wake turbulence, as it is illustrated in figure 10 is a well-known hazard to pilots. As a reminder, an aircraft generates wormholes that can be extremely dangerous for anyone who should be crossing them.

Figure 10 : Wake turbulence



These wormholes are all the more important because the generating aircraft is heavy, flies slowly and is a smooth configuration. They are generated backwards, have a slightly downward trajectory and are influenced by the wind.
The parry therefore consists in allowing a heavier aircraft to approach, to observe its trajectory carefully in order to deduce that of the wormholes and avoid them.
The taxiway capacity is one of the key elements of the configuration. This value, which is assumed to be 150m, is obtained by dividing the length of the link by the sum of the aircraft length and the safety distance. Since the connections in the apron area are approaching the complex taxiways, a slower speed of five knots is used while eliminating maximum capacity constraints.
If this is not possible, the following minimum separations must be respected (table 4)

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Lead/trail	L	M	H	J
L	80	52	45	45
M	80	52	45	45
H	80	52	45	45
J	80	52	45	45

Table 4 : Separation minima for departing aircraft (in seconds)

It is to minimize the risk of encountering wake turbulence that separation rules are applied between two aircraft. To facilitate implementation, aircraft are grouped into categories and separation minima are defined for a pair of categories. These minima are to be respected for an aircraft following or crossing the trajectory of another aircraft, in the approach and departure phase, when the vertical separation is less than 1,000 feet [16].

3.5. Behaviour in aircraft operation based on a speed coordination mechanism

In section 3.2.2., it is stressed that the resolution of the false impasse depends on coordination between aircraft. The resolution of some conflicts in advance, presented in expressions (4) - (7) of the model, also depends on coordination between aircraft.

In this context, the interlocking and synchronization of air operations are at the heart of the discussions.

Some additional symbols are given below :

τ_{A_0} The time interval required by the aircraft A_0 to reach its next node.

l_{A_0}, l_{A_1} Distance between the current position of the aircraft A_0 or A_1 its frontal node.

3.6 Event analysis and dynamic system update

Event simulation introduces the concept of " événement " to achieve a flexible time interval definition. An event represents the appearance of a possible change in the system status at a given time. Depending on the different aircraft positions in the taxiway, all possible events can be generalized in figure 11

The following are definitions of these two events.

Departure event : the aircraft A_1 left the Node N before departure or left the Node, but the aircraft A_0 cannot leave the Node due to the unsatisfied gap between the two departures see figure 11(a), (b).

In figure 11(a), opposite the aircraft A_1 has priority to leave the aircraft node A_0. The aircraft A_0 can go from the node to the junction. g^{dd} is satisfied between two aircraft. Consequently, the time interval can be calculated as follows

$$\tau_{A_0} = t^d_{A_1,N} + g^{dd} - t$$

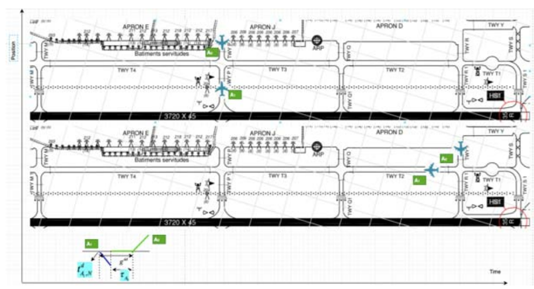

Figure 11a

For the case of figure 11(b), a similar expression can be given, only the spacing parameter is changed from h^{dd} and g^{dd} .

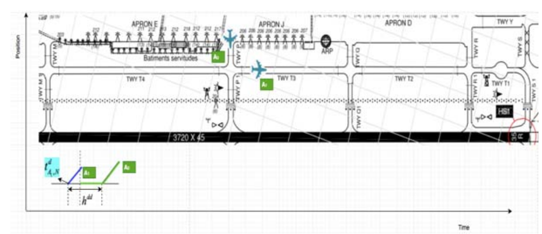

Figure 11b

Figure 11 a, b : possible events and corresponding time intervals

Depending on the definition of these two events, the $\tau^{\min}$ flexible time interval that is the minimum of all the events τ_{A_0} can be determined. Depending on the acquisition of aircraft speed and time interval, the system is updated progressively through aircraft movement modelling. In addition, it is necessary to determine whether aircraft time losses for acceleration and deceleration should be compensated when aircraft arrive and leave the Nodes. Once aircraft are required to stop at the Nodes, their arrival and departure times must be changed on time

3.7. Route Assignment

Frequently used routes and points of conflict before and after the flight rescheduling can be determined using a recent research project that proposes for the first time the introduction of detection and tracking technology using wireless acoustic sensor networks in the Mohammed V airport area. The solution

proposed by using different filters to predict the position of a target based on its measurement history. When the target is in a position, the leading sensor calculates the target position based on information gathered by nodes in its vicinity.
The airport platform is modeled as a graph with nodes and vectors, runway entry and exit are indicated in blue, stop in green and intersections in red. [13]
The proposed monitoring system can trace the paths taken by the aircraft at any time. This real-time data source will be of great help to us in order to know which paths are assigned before and after the traffic order. As well as to know the new point of conjunctions, this can lead to a reduction of conflict points.

4. NUMERICAL EXPERIMENTS ON A SIMPLE MODEL EXTRACTED FROM THE AIRPORT

The numerical experiments to test the quality of scheduling were divided into two steps :
The first step is to test the scheduling with taxiway capacity constraints on an airport surface according to a simple airport model extracted from Mohammed V airport as shown in figure 12. The departure route is shown in figure 12(a) and the arrival route is shown in figure 12(b).

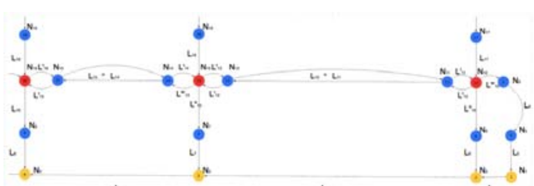

Figure 12a : Departure route

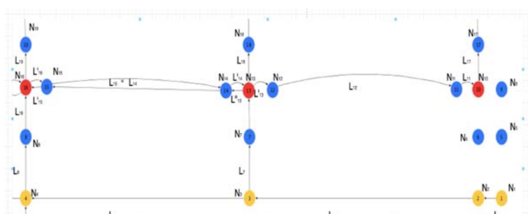

Figure 12b : Arrival route

Figure 12 a, b : Simple airport surface node-link model

To check, the planner, the capacity of all routes is set at five aircraft. The junction crossing time at all junction nodes is set at 20 seconds. Scheduling is shown in table 5.
The second step is to check the reliability of the programming of the "FCFS" and the "CDPG" on the same airport surface extracted from Mohammed V airport. The representation modeling is simple, composed of nine segments (taxiways) and ten Nodes (including intersections). Ten random instances are built to evaluate the performance of " CDPG " and " FCFS ". The length of each segment (taxiway) is evenly distributed between 200 m and 1000 m.
The CDPG proposed in Section 3 is implemented in python language and executed on MacOs using a machine with the performance, 2.2 GHz Intel Core i7 and 8GB RAM 1600 MHz DDR3.

4.1. Analysis of decisions taken and taxiway capacity constraints

Table 5 shows the scheduling results with link capacity constraints only. As expected, the delay is zero for the first four or five aircraft, as all routes are initially empty, but the delay begins to accumulate thereafter.

Table 5 A, B : Results Planning Without Crossing Or Wake Turbulence Constraints

Table 5a : Departure

N° Flight	Time	Delay(sec)	D/A
RAM964Y	00:00:00	0	DEP
RAM560Z	00:00:20	0	DEP
ANE19EU	00:00:30	0	DEP
IBB6401	00:00:40	0	DEP
JAF37J	00:05:15	275	DEP
UAE752	00:05:25	275	DEP
GFA020	00:07:25	385	DEP
JAF9WT	00:09:30	500	DEP
MAC477	00:11:30	610	DEP
RAM822	00:11:35	605	DEP

Table 5b : Arrival

N° Flight	Time	Delay(sec)	D/A
RAM469	00:00:20	0	ARR
RAM422J	00:00:30	0	ARR
JAF50A	00:00:40	0	ARR
RAM795Z	00:00:50	0	ARR
RAM219	00:01:00	0	ARR
RAM500B	00:02:55	125	ARR
TAR711	00:05:05	245	ARR
RAM486	00:07:05	355	ARR
MAC993	00:07:10	350	ARR
RAM965Y	00:09:10	460	ARR

Figure 13 shows the distribution of the number of aircraft on routes L12 and L14 as a function of time.
As shown in figure 12, the L14, L15 links are adapted to traffic in both directions. It can be seen in figure 13(a) and 13(b) with alternating negative and positive counts. The L14 link is only used for the arrival route and only displays negative counts,

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The L12 link in figure 12 is used only for the departure route and only displays positive counts, indicating a one-way operation.

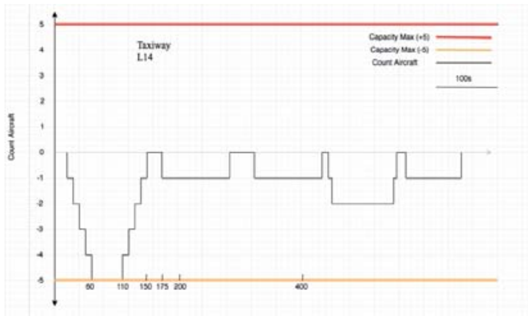

Figure 13a

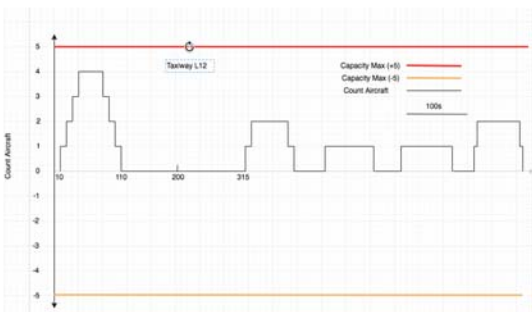

Figure 13b

Figure 13 a, b : Aircraft counts and capacity constraints in Taxiway L12 and L14

4.2. Analysis of FCFS and CDPG aircraft movement decisions

To reflect the difference between the FCFS and the CDPG, figure 14 presents examples of aircraft diagrams based on these two different mechanisms. As shown in figures 16(a) and 16(b), different travel strategies are used to resolve conflicts.

C_{A_0,A_1} Between aircraft A_0 and A_1, what happened in the segment L_5. The aircraft A_1 arrives freely at the segment L_5 at 220 s, and the aircraft's arrival time A_0 is 240 s. According to the FCFS rule, the aircraft A_1 will arrive before the segment because of L_5 its early arrival (see figure 14(a)).

The total delay of all aircraft is 1024 s in the schedule. In the CDPG, aircraft movement strategies are determined based on the forecast of conflict distribution in the subsequent flow plan. When the aircraft A_1 first occupies the segment L_5, the total delay is approximately 1024 s in the next schedule obtained by the local priority rule. However, if the aircraft A_1 adopts a stopping strategy, the total delay is approximately 956s. Obviously, the aircraft A_1's "stop" strategy is as follows.

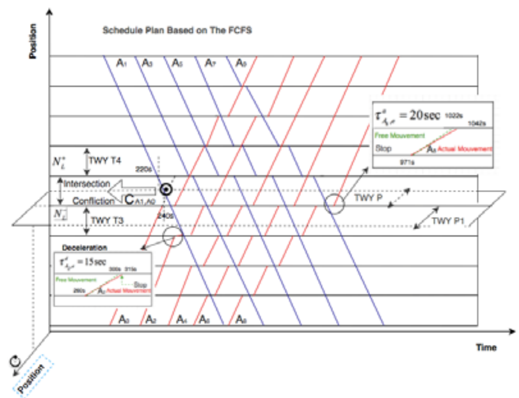

Figure 14a : FCFS approach

A better distribution of conflicts can be achieved in a subsequent scheduling plan. The total delay of all aircraft is 976s in the final scheduling plan (figure 14(b)). It also proves that the aircraft shutdown strategy A_1 may be more appropriate to resolve conflicts C_{A_0,A_1} than the "on the move" strategy.

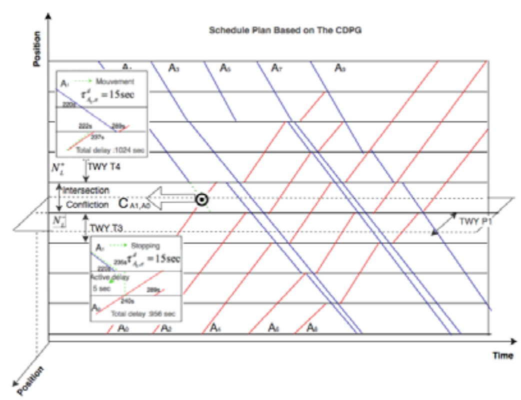

Figure 14b : CDPG approach

Figure 14 a, b : The schedule plans obtained by two approaches

As shown in the constraints (6) in section 2.2, aircraft time losses for acceleration and deceleration are discussed in this document. The iconography I in figure 14(a) explicitly represents the shift in the aircraft's acceleration time in the A_8 segment between the position N_5 and N_6. The

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aircraft A_8 departed the node N_5 at 971 s and arrived at the node N_6 at 1022 s. However, due to the aircraft stopping A_8 at the node N_5, the aircraft's loss of acceleration time A_8 must be compensated. Thus, the aircraft's arrival time at A_8 the node is N_6 actually 1042s. Like iconography I, iconography II explicitly represents the shift in the aircraft's deceleration time A_2 in the segment due to its stop at N_4.
Finally, it focuses on aircraft delay characters in the CDPG. Two iconographies in figure 14(b) explicitly describe two different aircraft movement strategies A_1 to resolve a conflict between A_0 and A_1. Iconography I in figure 14(b) shows that the movement strategies of A_0 and A_1 are determined by local priority rules, and iconography II shows the movement decisions of A_0 and by A_1 the CDPG. In iconography II, the aircraft A_1 arrives at the node N_4 at 235s, and the aircraft A_0 arrives at the node N_3 at 240s. Obviously, in terms of aircraft delay characters, the A_1 actively stops at the node N_4 about 5s. However, the total delays of all aircraft are reduced to about 69s. Obviously, the active delay due to A_1 the node N_4 can lead to better conflicts in the next scheduling plan. Figure 14(b) also shows that the distribution of conflicts in the CDPG is similar to the optimal distribution.

5. CONCLUSION

To improve traffic flow management, the FCFS planner originally introduced has been improved with two additional features that allow it to be applied to the airport surface movement planning. The directionality problem of the links encountered has been fixed by introducing a concept of negative aircraft counting. Intersection conflicts existing have been treated with node flow constraints. Furthermore, route assignment capability, which can evaluate up to five different routes, has been added so that the planner can be used with the dynamic routing concept. The FCFS planner was verified using a simple airport model. Several scheduling experiments were conducted using simulation data on surface movement.
The ASCP is examined in a single-track case (taxiway). Mathematical formulation is a complex non-linear programming in mixed integers. This takes into account a system of constraints, such as spacing, travel times and track capacity. The object of the model is non-linear. It reflects the sensitivities of aircraft of different types or routes flown on the delay. The model also ensures that the number of aircraft does not exceed track capacity at any time. To avoid discretizations of the time horizon, a track selection variable is introduced into the track capacity without constraint. In addition, the model takes into account some separation constraints, such as Arrival-Arrival, Departure-Departure, Departure-Arrival, Arrival-Departure, Arrival-Departure, and wake turbulence. These constraints are also close to the actual operation within the airport platform.
Due to the non-linearity of the object and a large number of binary variables, the model cannot be solved by adopting an exact algorithm when it comes to a large-scale instance.
A heuristic approach based on the global Conflicts-Distribution-Prediction Ground (CDPG) method is presented. It is in fact the result of a dynamic event-driven system. The CDPG addresses two key issues : aircraft deadlock and near-optimal aircraft movement strategies. First, the mechanism of the blockage formation is analysed in detail. Based on the analysis of the aircraft deadlock formation mechanism, a deadlock verification procedure is presented, which effectively avoids the formation of the aircraft deadlock. The aircraft speed coordination mechanism avoids the formation of "false" impasses. Secondly, the mechanism for optimizing the aircraft movement strategy is presented on the basis of the prediction of the distribution of global aircraft conflicts. Aircraft movement strategies are determined based on the distribution of conflicts in the following schedule.

The focus of a future works is to create other acoustic detection systems to locate and track moving objects on airport surfaces. This is mainly due to the fact that, unlike radar scanning, acoustic detection can be carried out using fully passive sensors by listening only to the noise of the target.

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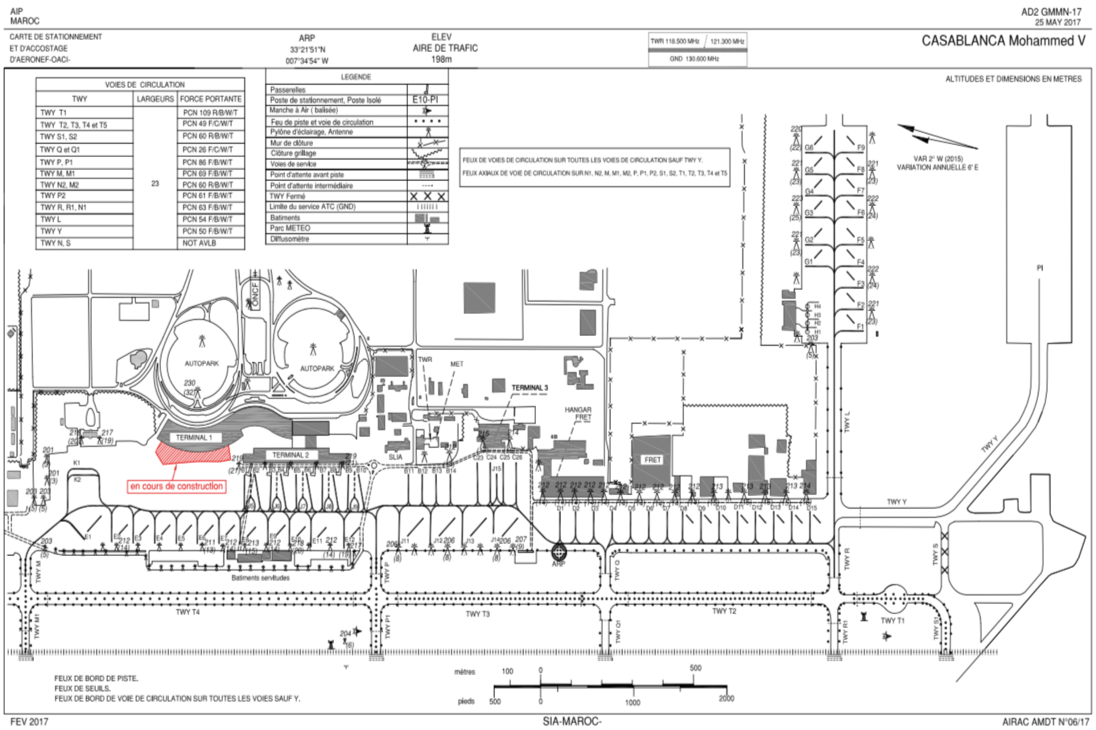
ANNEXES



Annexe 1 : Parking map at Mohammed V Airport

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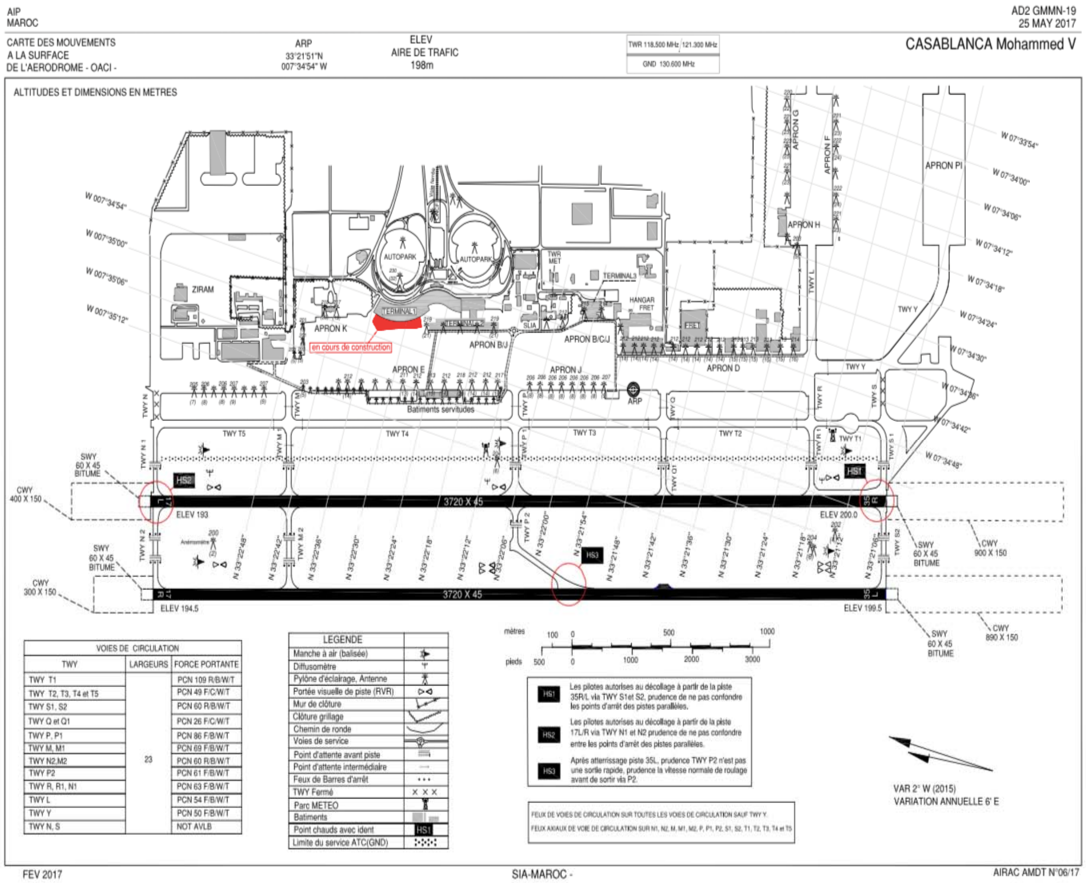

Annexe 2 : Map of movements at Mohammed V Airport

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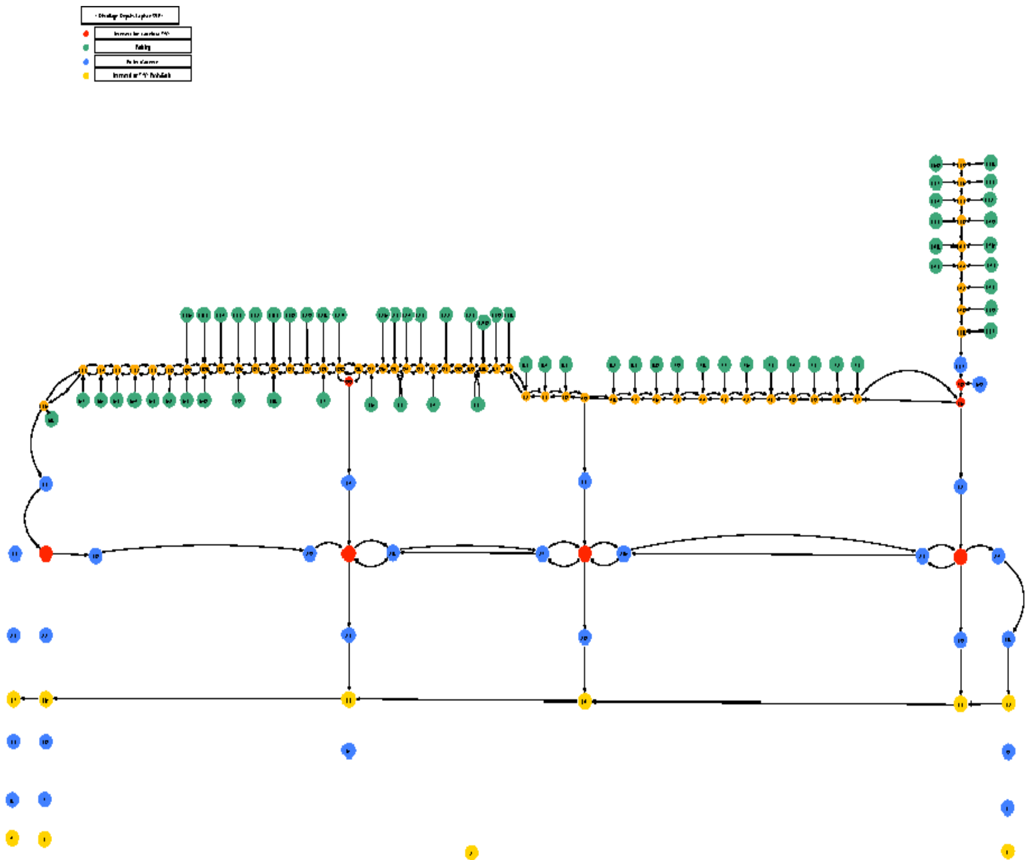

Annexe 3 : Take-off scenario at Mohammed V Airport

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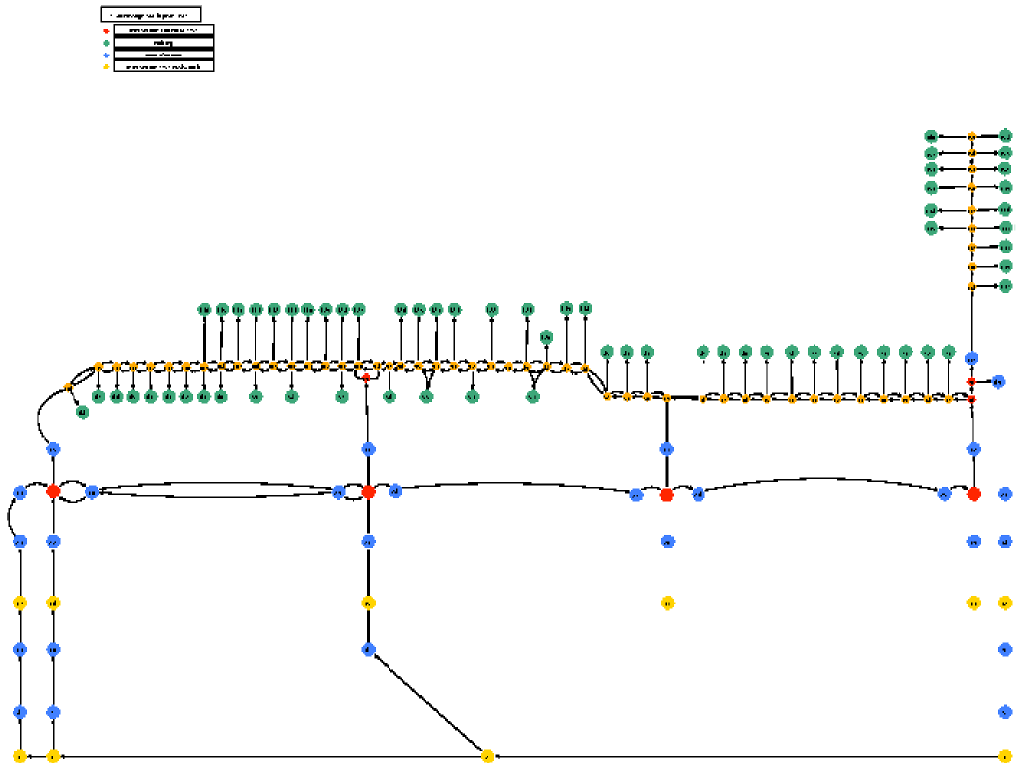

Annexe 4 : Landings scenario at Med V Airport